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Geobiological impacts of Earth's early complex bioturbators during the Ediacaran-Cambrian transition

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The evolution of complex bioturbation during the Ediacaran-Cambrian transition (ca. 550 – 515 Ma) is commonly thought to have oxygenated sediments via removal of microbial mats and sediment mixing, forever changing many of Earth's key biogeochemical cycles and expanding available benthic ecospace for macrofauna radiations in the Cambrian. However, few previous studies have considered the emerging record of different bioturbation behaviors and intensities from the Ediacaran-Cambrian trace fossil record. Specifically, there is a need for more focus on the abundances of biomixing and bioirrigation in the trace fossil record, two behaviors that can have opposite effects on sediment redox chemistry. Here, we provide evidence for changes in bioturbation behaviors in a well-known Ediacaran-Cambrian succession in eastern California to discretely parameterize bioturbation for use in reactive-transport modeling to investigate the effects of bioturbation on sediment geochemistry across the Ediacaran-Cambrian transition.

We focus on the early Cambrian trace fossil record of biomixing (solid particle reworking) and bioirrigation (burrow ventilation) from the Deep Spring Formation, California, USA as a case study for how early bioturbators impacted carbon, oxygen, and sulfur dynamics. We characterized each ichnogenus as a biomixing or bioirrigation behavior based on its ecological context (e.g., interpreted feeding behavior) and mapping analyses of redox-sensitive elements across the burrow structures using micro-XRF. We constrained intensities of biomixing and bioirrigation based on relative abundance of biomixing to bioirrigation ichnogenera and ichnofabric indices of each collected trace fossil slab. Using these ecological and geochemical constraints, we generated distributions of bioturbation parameters to describe a range of possible biomixing and bioirrigation intensities. We integrated these parameter distributions with a reactive-transport model to conduct Monte Carlo simulations to predict sediment geochemistry profiles that likely resulted from the activities of bioturbators represented in the Deep Spring Formation. Ultimately, we found an abundance of biomixing trace fossils in the Deep Spring Formation, which would have caused a slight shoaling of the oxygen penetration depth and an increase in hydrogen sulfide production in the shallowest sediment tiers. These results establish a new model for how early Cambrian bioturbators impacted sediment biogeochemistry and benthic ecosystem functioning during the Early Paleozoic.